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THESIS

DEVELOPMENT LENGTH OF MULTIPLE FIVE-STRAND TENDONS

IN POST-TENSIONED SLABS

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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The objective of this thesis is to determine the bonded development length of multiple 5-strand tendons with surrounding concrete in post-tensioned slabs. The prestressing steel is 7-wire strand grade 270 K diameter 0.5 inch (12.7 mm). The bond between concrete and multiple strands are developed to produce the prestressing force replacing the anchorage force after the loss of anchorage. The relationship between bonded length and the concrete compressive strength is determined by test of 21 concrete blocks stressed by multiple 5-strand tendons with anchorage at both ends. The concrete compressive strengths of 240, 280, 320 and 380 ksc are casted in the blocks to cover strands, then the anchorage is cut and the bonded length is determined to develop sufficient tensile force instead of anchorage force.

The results show that the bond between the multiple strand tendons and covering concrete can be used to replace the anchorage stressing force. The bonded length of multiple strand tendons decreases when the concrete compressive strength increases. The transfer length from tests are close to the length by ACI equation at the compressive strength of 280 ksc and less than 10% for the other compressive strength. All recommended bonded development lengths from test are less than the computational length by codes because the long term effects are not considered in test. The bonded length of the multiple 5-strand tendons is longer than the multiple 3-strand tendons and should be conservative to be the representative for bonded length of all multiple strand tendons in practice.

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Student's signature Thesis Advisor's signature

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Wiroj Atipornwanich

June 2011

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF NOTATION AND DEFINITIONS

Notation and definitions of the terms are

d_b = nominal diameter of prestressing strand

f'_{ci} = initial concrete compressive strength at transfer

f_{ps} = stress in prestressing steel at nominal flexural strength

f_{pu} = ultimate tensile strength of prestressing steel

f_{se} = effective stress in prestressing steel (after all prestress losses)

f_{si} = stress in prestressing steel immediately after prestressing force has been applied to concrete

f_{su} = average stress in prestressing steel at ultimate load

L_b = flexure bond length of prestressing steel

L_d = development length in tension of prestressing steel

L_t = transfer length in tension of prestressing steel

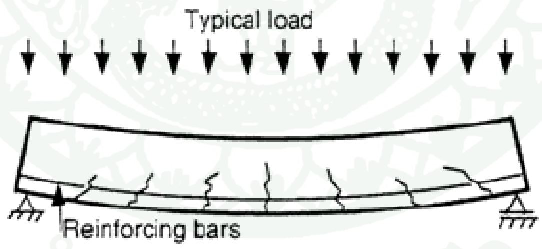
ϕ = strength reduction factor

DEVELOPMENT LENGTH OF MULTIPLE FIVE-STRAND TENDONS IN POST-TENSIONED SLABS

INTRODUCTION

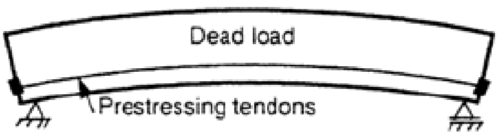
At present, the bonded post-tensioning system, a type of prestressed concrete, is widely used as floor structural system of building in Thailand. The post-tensioning floor system is commonly used in commercial building, department store, residential, apartment, high-rise condominiums, hotel, office building and parking building.

The prestressed concrete has been developed as structural system. Prestressing is a method to increase the strength of concrete member to counteract the applied loads during the anticipated service life of the member.

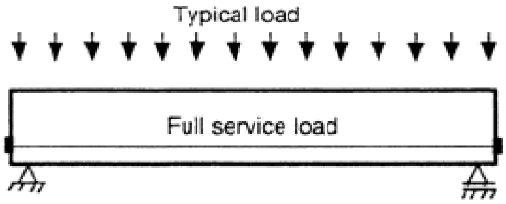


(a) Reinforced concrete

Figure 1 The structural behavior of reinforced concrete and prestressed concrete member on carry loads.



(b1) Prestressed concrete, at transfer

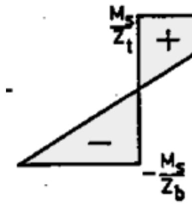


(b2) Prestressed concrete, at service load

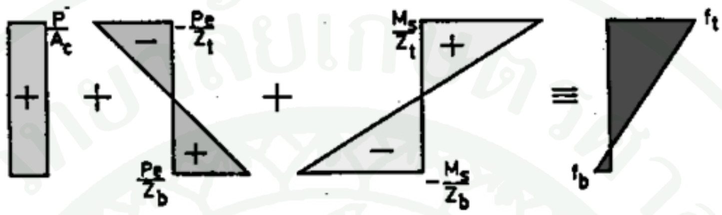
Figure 1 (Continued)

Source : Chompreda (2007)

The example of prestressed concrete member is expressed and compared to the reinforced concrete member as shown in Figure 1 (Chompreda, 2007). For the reinforced concrete member after the member carrying loads, by the structural behavior, the member is deflected and cracks caused by flexural tensile stress in concrete are developed as shown in Fig.1*a*. The reinforcing of rebar is provided to resist tensile stress of the section as shown in Fig.2*a*. For the prestressed concrete member, the structural behavior can be explained into two steps. In the first step, called *"at transfer"* as shown in Fig.1*b1*, the strength of member is provided by prestressing steel to counteract the stresses developed by the dead load of member. The member is cambered by the eccentric moment of prestressing steel. In the second step, called *"at service load"* as shown in Fig.1*b2*, the strength of member is developed to carry the service loads, superimposed load and live load. The second step deflection is balanced by the camber in first step and result in less deflection totally.



(a) Reinforced concrete

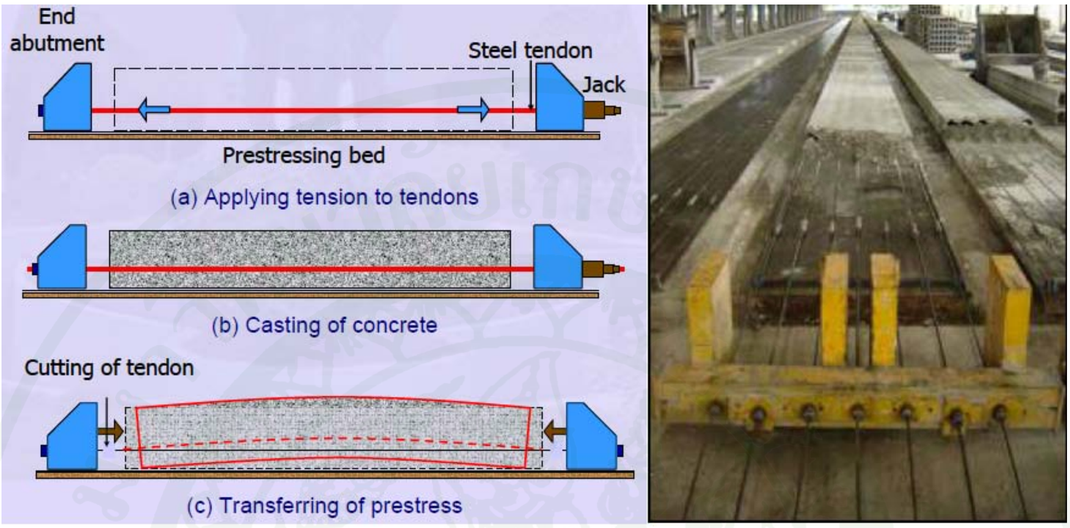


(b) Prestressed concrete

Figure 2 Stress distribution on the cross section of reinforced concrete and prestressed concrete member (negative sign for tensile stress).

Cracks as shown in Fig.1*b1* and Fig.1*b2* are controlled to be the uncracked section by calculating the net tensile stress of the section to be minimum as shown in Fig.2*b*. The value of net tensile stress must be less than the allowable tensile stress by ACI code.

The prestressed concrete is classified into two types according to the stage of stressing steel tendon compared to the time of casting concrete. The first type is pre-tensioning system where the steel tendons are stressed prior to concrete placement as shown in Figure 3. The stages of pre-tensioning are shown in Fig.3.1 ([1]Sengupta and Menon, n.d.) in the sequences as (a) placing steel tendons and applying tension to the tendons, (b) casting of concrete and curing, (c) cutting the tendons to transfer force of prestressed into the concrete member. Fig.3.2 shows a product of pre-tensioning system, hollow-core slab as an example ([2]Siam Cement Group, n.d.).



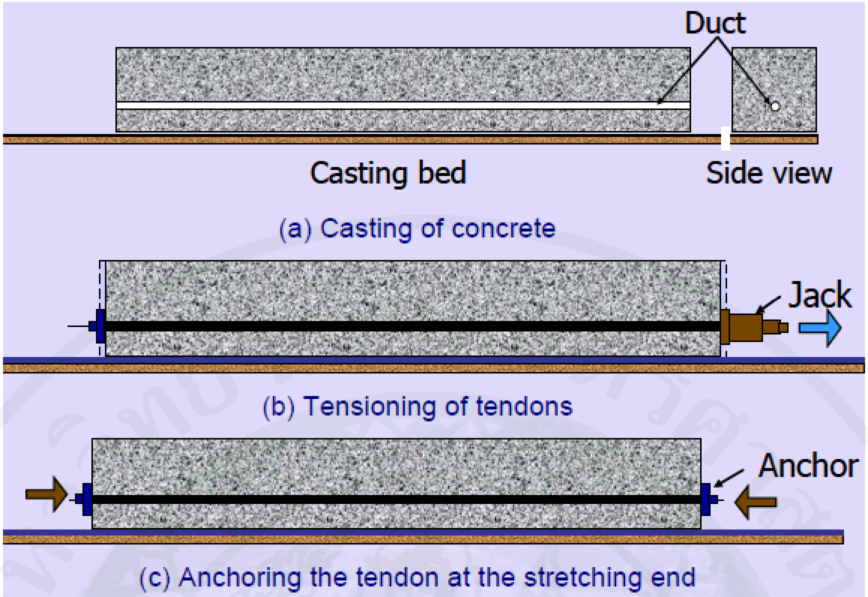
(3.1) Stages of pre-tensioning[1] (3.2) Pre-tensioned hollow-core slab[2]

Figure 3 Pre-tensioning system.

Source : [1]Sengupta and Menon (n.d.)

[2]Siam Cement Group (n.d.)

The second type is post-tensioning where steel tendons are stressed after the concrete has been placed as shown in Figure 4. The stages of post-tensioning are shown in Fig.4.1 ([1]Sengupta and Menon, n.d.) in the sequences as (a) placing prestressing steel tendons, casting of concrete and curing, (b) tensioning of tendons, (c) anchoring the tendons at the stretching end to permanent fixed anchors and transfer force of prestressed into the concrete member. Fig.4.2, Fig.4.3 and Fig.4.4 show the steps of post-tensioned slab construction at site ([2]Post & Precast co.,Ltd., 2003).



(4.1) Stages of post-tensioning[1]

(4.2) Placing tendons[2]

(4.3) Casting of concrete and curing[2]

Figure 4 Post-tensioning system.

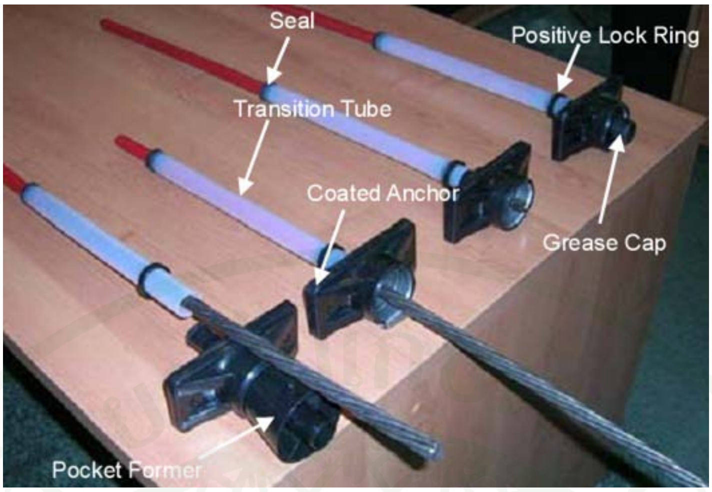
(4.4) Stressing tendon, tensioning of tendons and fixing of anchorage[2]

Figure 4 (Continued)

Source : [1]Sengupta and Menon (n.d.)

[2]Post & Precast co.,Ltd. (2003)

The second type, post-tensioning system, can be classified into two types. The first one is unbonded tendon, the prestressing steel is prevented from bonding and free to move relative to the surrounding concrete as shown in Fig.5a and Fig.6a ([1]Gupta, n.d.). The second one is bonded tendon in which bonding of surrounding concrete occurs by grouting cement after steel tendon was stressed as shown in Fig.5b and Fig.6b ([2]Post & Precast co.,Ltd., 2003).



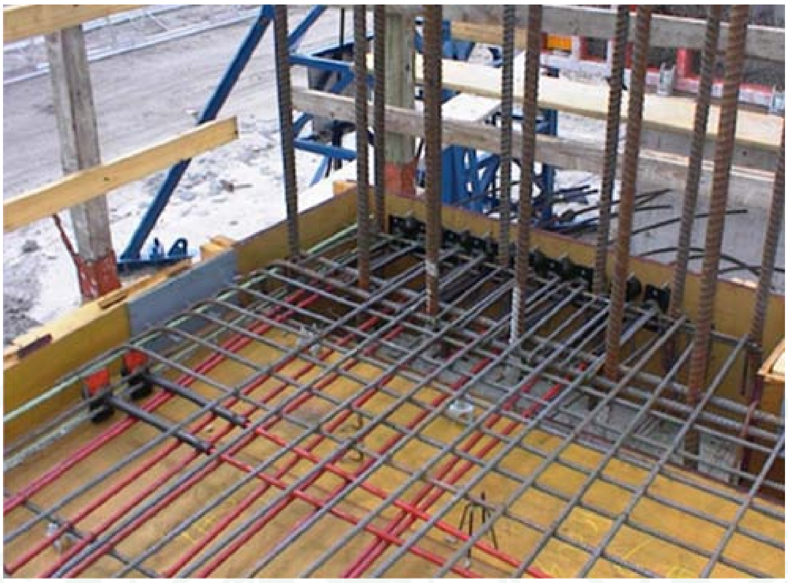
(a) Unbonded system[1]

(b) Bonded system[2]

Figure 5 Post-tensioning system type unbounded and bonded systems.

Source : [1]Gupta (n.d.)

[2]Post & Precast co.,Ltd. (2003)



(a) Unbonded tendons[1]

(b) Bonded tendons[2]

Figure 6 Tendon types unbonded and bonded tendons.

Source : [1]Gupta (n.d.)

[2]Post & Precast co.,Ltd. (2003)

The type of prestressed concrete system can be summarized by the flow chart as shown in Figure 7.

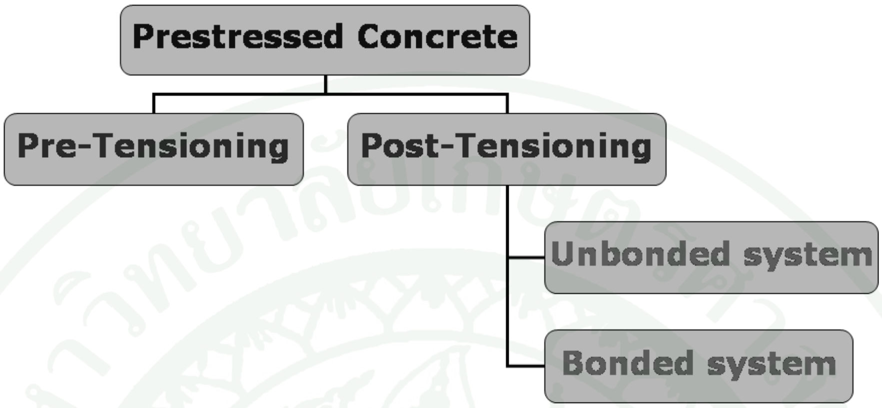


Figure 7 Flow chart of prestressed concrete system.

Post-tensioned concrete floors have more advantages in comparison to conventional reinforced concrete floors and pre-tensioned hollow-core slabs. The benefits are long spans, higher free height of floor level, higher load carriage, controlled deflection, rapid construction, economics etc. Nowadays, The post-tensioned concrete floors, bonded system, tendons are widely used in Thailand because the advantages are less maintenance problem in long term, easier and safe to add small opening or sleeve in the future and better in fire endurance when compared to unbonded tendons.

However bonded post-tensioned concrete floors have a disadvantage that a revision or modification of the concrete floor is not feasible. The revision after the completion of construction and grouting may cause the tendons to lose stress by anchorages loss. The remaining strength of tendons depends on the quality and adequacy of grouting.

Figure 8 shows the example of the problem arisen when the edge of bonded post-tensioned concrete floor was cut off. Fig.8*a* shows the concrete slab before revision or modification. Fig.8*b* shows the concrete slab after cutting off the slab edge. The lost of the anchorages at left end of slab affects the mechanism system of remaining tendons for transferring prestressed force into concrete slab. The new anchorages can not be replaced or re-stressed because the grouting was completed.

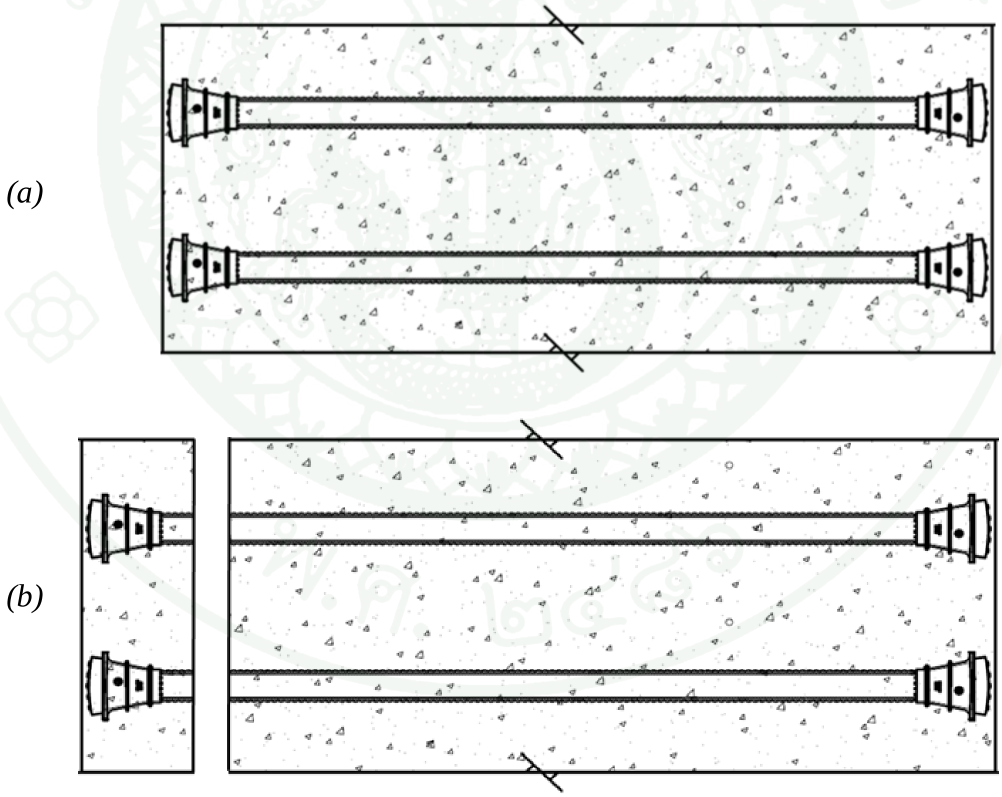
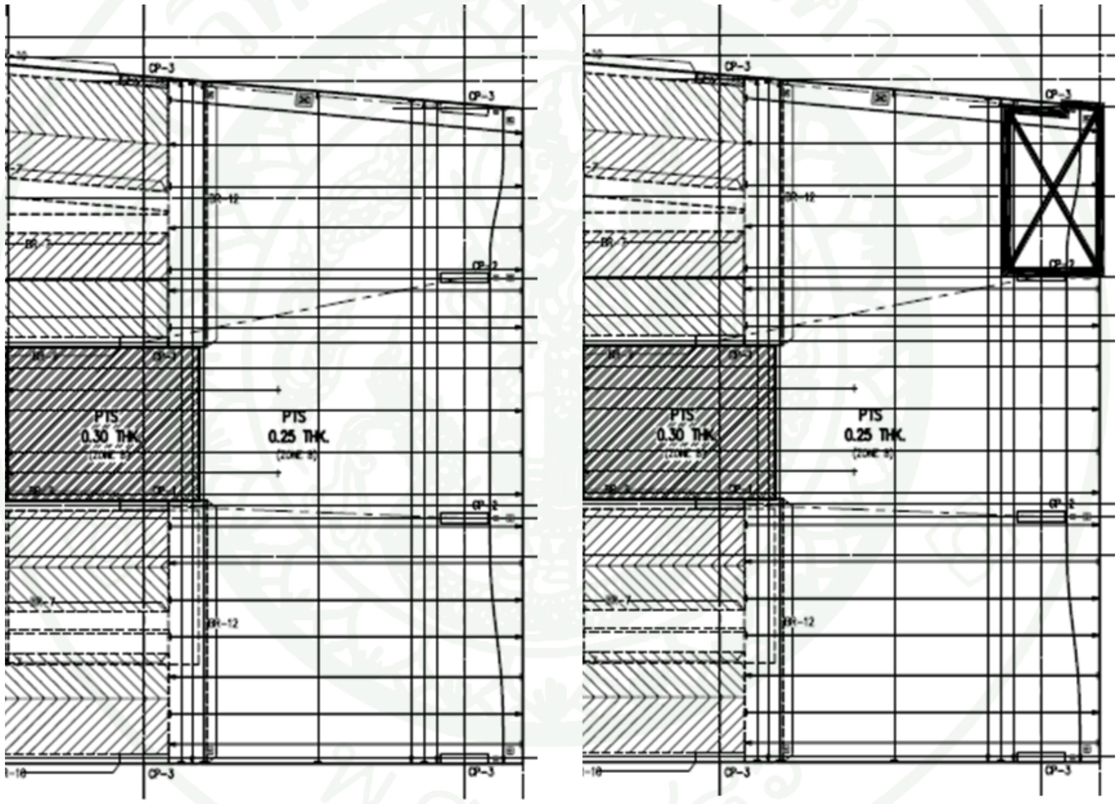


Figure 8 The edge of bonded post-tensioned concrete slabs cut off because of the revision or modification of slab.

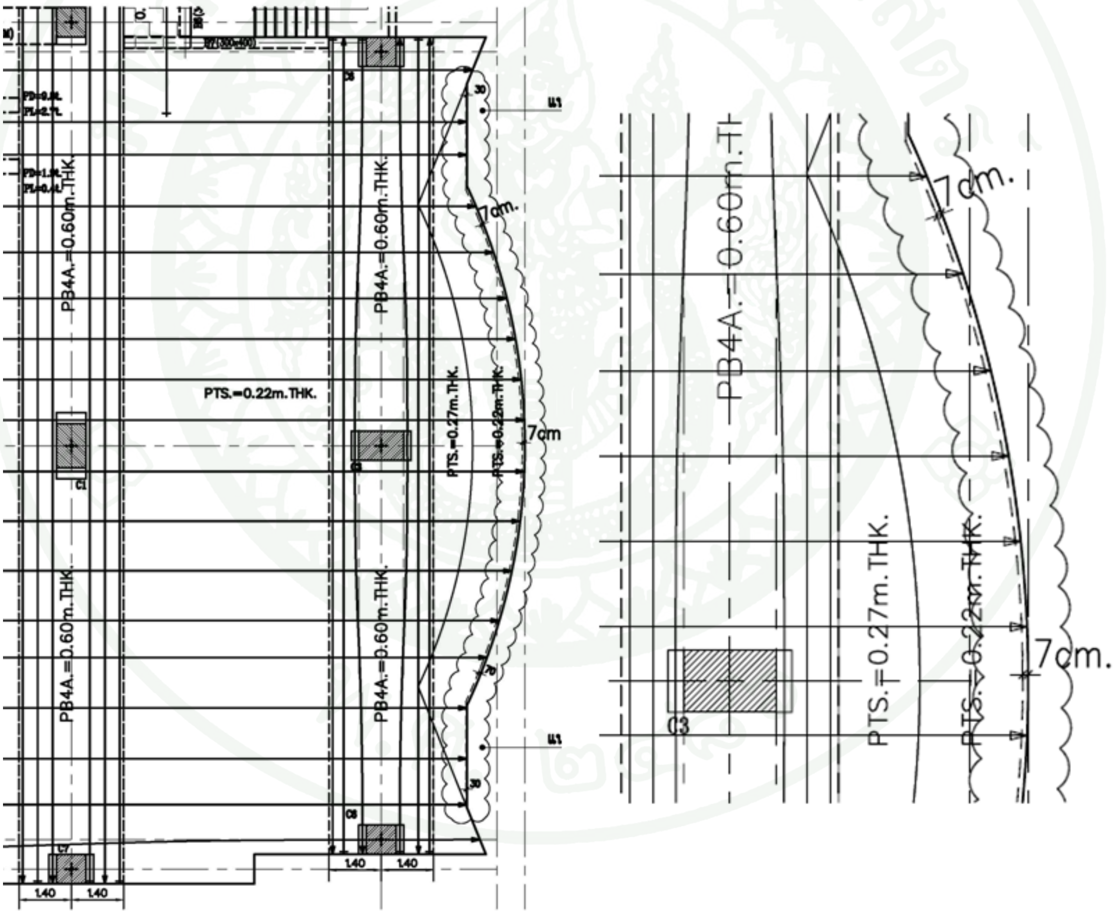
Figure 9 shows the case study of the problem in bonded post-tensioned concrete floor. Fig.9*a* is the completion of construction of parking concrete floor. Fig.9*b* shows the requirement to open new stairway for fire escape purpose. The fire escape stairway is required by the ministerial regulation which is also applied to old public buildings. So, some area of parking concrete floor must be cut out to add staircase opening.



(a) *(b)*

Figure 9 The corner of bonded post-tensioned concrete floor cut off to open for fire escape stairway.

Figure 10 shows another case of problem in bonded post-tensioned concrete floor. Fig.10*a* shows the completion of construction of typical story concrete floor. During architectural work, the contractor found the mistake of construction of one story where the edge of slab was larger than the other typical stories. Fig.10*b* shows the 7 cm larger edge of slab. Even though 7 cm is small, it is different from the other typical stories after finishing architectural work, so cutting the edge of concrete floor is required.



(a) *(b)*

Figure 10 The requirement to cut the edge of slab which is larger than other typical stories.

The remaining strength of tendons after anchorage loss depended on the quality and adequacy of grouting. Grouting is a compound of Portland cement and water within the sheath. Grouting does not have aggregates. Bonding between prestressed steel and grouting surrounding is developed after tendons lose fixing by anchorage. However, bonding of grouting is insure in quality and adequacy because grouting can not be visible on the floor and is unable to prove in bonding strength. Low quality and inadequate standard of grouting caused by workmanship or human error affects the strength and durability in the long term.

The post-tensioned slabs should not be cut because tendons might lose fixing by anchorages and lead to losing the strength of prestressed concrete. The revision or modification of the concrete floors should be done by architectural change and should avoid cutting of the floor slabs for the safety of structures. For a worst case situation that can not be avoidable, a method of replacing of concrete covering tendons is used to replace the anchorage stress. The overall structural design of concrete floors have to be considered, i.e., flexural of strength, shear and deflection. The local structures of the replacing of concrete covering tendons might not be fully prestressed concrete anymore. However at present there is no theoretical method to calculate the bonded development length for multiple strand tendons.

This thesis aims to determine the bonded development length of newly caste concrete covering prestressing steel tendons to replace grouting. The new covering casted concrete can be visible for inspection during casting. Good control of workmanship and mixture can increase compressive strength and bonded development length to ensure the same tensile stressing by concrete covering instead of the anchorages loss.

OBJECTIVES

The objective of this thesis is the experiment study to determine the bonded development length of multiple five-strand tendons with surrounding concrete in post-tensioned slabs. The prestressing steel is 7-wire strands grade 270 K diameter 0.50 inch (12.7 mm). The bond between strands and concrete are developed from the tensile stress of prestressing force to replace the anchorage force after the loss of anchorage.

The relationship between bonded development length and the concrete compressive strength is determined by concrete block samples stressed by multiple five-strand tendon with anchorage at both ends. The test method is started by casting the concrete to cover multiple strands into the prepared opening box. After obtaining the desired compressive strength of concrete, cut at anchorage at one end and determine the bonded length that is sufficient to develop tensile force replacing anchorage loss.

For bonded post-tensioned concrete floors, tendons are multiple strands placed in a flat duct from two and up to five strands. In this thesis, the multiple five-strand tendons are chosen to be the representative to determine bonded development length because of the largest value of tension.

The objective is summarized as follows.

1. To present the acceptable bonded development length of prestressing steel type 7-wire strands grade 270 K diameter 0.5 inch (12.7 mm) sufficient to develop tensile force equivalent to the anchorage force after the loss of anchorage.

2. To determine the relationship between the concrete compressive strength and bonded development length found in item no.1.

3. To compare the results of item no.1 with the values proposed in the codes and standards.

Scope of Study

1. The long term effects, i.e. , shrinkage, creep, different covering of concrete, bonded stress due to flexural, shear and cracks in the test of bonded development length are not considered.

2. The desired compressive strength of concrete is 240, 280, 320 and 380 ksc.

3. Type of strands in test used the 7-wire strand grade 270 K diameter 0.5 inch.

4. Type of tendon in test used 2 types that are the multiple five-strand tendons and multiple three-strand tendons

5. Number of specimens is 3 samples for each type of the compressive strength of concrete and 21 samples totally.

6. Age of concrete when cutting the strand and anchorage depended on the desired compressive strength. The test used the historical record of the compressive strength test of concrete plant to expect the age of cylinder concrete specimens for tested compressive strength.

7. The slip is based on visible and compared to the marking of reference point.

8. No grouting and duct are considered in test.

LITERATURE REVIEW

The development length of prestressing steel is presented in four references. The first one is **“**Building Code Requirements for Structural Concrete, ACI 318”, the second one is “Design of Prestressed Concrete Structures by T.Y.Lin and Ned H. Burns”. The third one is **“**Standard Specifications for Highway Bridges, AASHTO” and the last one is “PCI Design Handbook”.

1. Building Code Requirements for Structural Concrete (ACI 318)

American Concrete Institute (2008) proposes the formula (Eq.12-4 in section 12.9, ACI 318-08) for the prestressing steel type 7-wire strand to provide a distance of development of prestressing strand not less than the following (Imperial unit, psi and inch).

$$L_d = \left(\frac{f_{se}}{3000}\right) d_b + \left(\frac{f_{ps} - f_{se}}{1000}\right) d_b \quad (1)$$

Notation and definitions of the terms are

L_d = development length in tension of prestressing steel (inch)

d_b = nominal diameter of prestressing strand (inch)

f_{se} = effective stress in prestressing steel (after all prestress losses, psi)

f_{ps} = stress in prestressing steel at nominal flexural strength (psi)

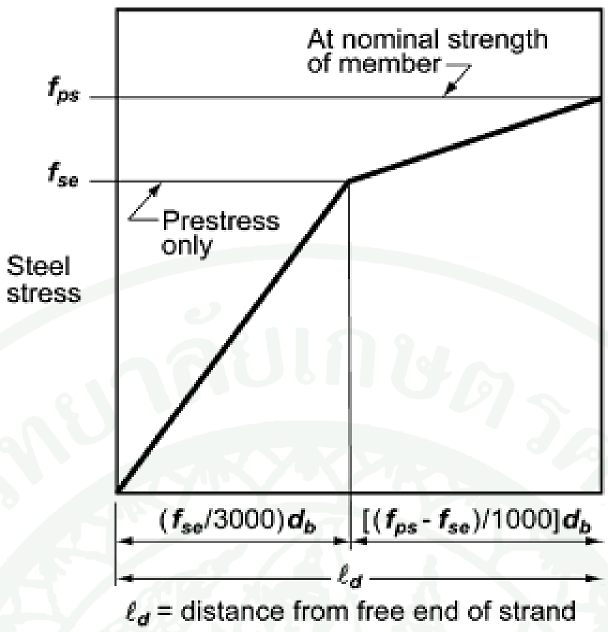


Figure 11 Relationship between steel stress and distance from the free end of strand.

Source : American Concrete Institute (2008)

Figure 11 shows the relationship between steel stress and the strand distance bonded to the concrete as shown in Equation (1). The first term of Eq.(1) represents the transfer length (L_t) of strand which should be bonded over the effective force. The second term represents the additional length of strand which should be bonded over the developed nominal strength of member (L_b).

By using Eq.(1), the distance of development of prestressing strand (L_d) for 7-wire strand diameter 0.5 inch (12.7 mm) is about 210 cm at breaking strength 18.73 ton. The distance of the transfer length (L_t) 66 cm and the flexural bond length (L_b) 144 cm is combined when calculated by using effective force of strand 10.8 ton and strand area of 99 sq.mm. Nevertheless this formula is used for a bonded distance of single strand in pre-tensioned concrete. For the bonded post-tensioned concrete, multiple two and up to five strands per tendon are normally used in construction.

2. Design of Prestressed Concrete Structures (Lin T. Y. and N. H. Burns)

Lin and Burns (1982). Design of Prestressed Concrete Structures, express the formula (Eq.7-24 section 7-6) to provide a development length of prestressing steel for the moment from critical section. A distance to develop tensile stress from the critical section is shown as follows (SI unit, MPa and mm).

$$L_d = \left(1.5\frac{f_{si}}{f'_{ci}}d_b - 117\right) + 0.181\left(f_{pu} - f_{se}\right)d_b \quad (2)$$

Notation and definitions of the terms are

L_d = development length in tension of prestressing steel (mm.)

d_b = nominal diameter of prestressing strand (mm.)

f'_{ci} = initial concrete compressive strength at transfer (MPa)

f_{si} = stress in prestressing steel immediately after prestressing force has been applied to concrete (MPa)

f_{se} = effective stress in prestressing steel (after all prestress losses, MPa)

f_{pu} = ultimate tensile strength of prestressing steel (MPa)

Equation (2) is similar to Equation (1) except the compressive strength (f'_c) is included in Eq.(2). Table 1 shows the development lengths that are calculated by Eq.(1) and Eq.(2). Table 1 shows that the calculated lengths by Eq.(2) are greater than that given by Eq.(1) of ACI 318-08.

Table 1 Comparison between the development length (cm) that is calculated by Eq.(1) and Eq.(2) of single 7-wire strand.

Description	transfer length (L_t)	flexural bonded length (L_b)	development length (L_d)
1. L_d by Eq.(1), ACI 318	66	144	210
2. L_d by Eq.(2), base on f'c 320 ksc	78	181	259

3. Standard Specifications for Highway Bridges (AASHTO)

American Association of State Highway and Transportation Officials, Inc (1996) proposes the embedment of prestressed strand (Eq.9-32 section 9.28) for the 3-wire or 7-wire pretensioning strand shall be bonded beyond the critical section for a distance of development length not less than the following (Imperial unit, kips and inch).

$$Ld = \left(fsu - \frac{2}{3} fse \right) db \qquad (3)$$

Notation and definitions of the terms are

l_d = development length of prestressing steel (inch)

d_b = nominal diameter of prestressing steel (inch)

f_{se} = effective steel prestress after losses (kips per square inch)

f_{su} = average stress in prestressing steel at ultimate load (kips per square inch)

This Eq.(3) of AASHTO is same as the Eq.(1) of ACI 318-08 but it has a little difference of definitions, arrangement of the formula and unit of steel stress.

4. PCI Design Handbook.

Precast/Prestressed Concrete Institute (2004) proposes the strand development for a pretensioned member (Eq.4.2.3.1 section 4.2.3) that prestressed force transfers to the concrete by bond. The length required to develop the design strength of the strand is much longer than the following (kips and inch unit).

$$L_d = \left(\frac{f_{se}}{3}\right) d_b + \left(f_{ps} - f_{se}\right) d_b \tag{4}$$

Notation and definitions of the terms are

L_d = development length in tension of prestressing steel (inch)

d_b = nominal diameter of prestressing strand (inch)

f_{se} = effective stress in prestressing steel (after all prestress losses, kips per sq.inch)

f_{ps} = stress in prestressing steel at nominal flexural strength ((kips per sq.inch)

This Eq.(4) of PCI Design Handbook is same as the Eq.(1) of ACI 318-08 but it has difference in unit of prestressing steel stress.

RESEARCH METHODOLOGY

1. Hypothesis

1.1 Bonded development length should decrease when fc’ increases.

1.2 The largest type, multiple five-strand tendons, shall be the critical type of bonded length test because of its largest value of tension.

1.3 Bonded length test should begin by using at first the longer length than the transfer length in Table 1, then decrease the length during the test to find the minimum length. In test, decreasing is easier than increasing of the concrete length. Therefore, the 90 cm of concrete length should be considered as good starting length.

1.4 If possible, the test is based on unbonded condition to prevent the poor quality and inadequacy of grouting that may occur due to poor workmanship in field work.

2. Materials and Equipment

2.1 Materials

2.1.1 Concrete with desired fc’ of 240, 280, 320 and 380 ksc

2.1.2 Rebar type SD40 and SR24

2.1.3 Seven-wire strands grade 270 K, diameter 0.5 inch (12.7mm)

2.1.4 Bonded post-tensioned hard-ware and accessories

2.2 Equipment

2.2.1 Jacking machine consisting of hydraulic jack and hydraulic pump with maximum capacity 20 ton.

2.2.2 Grinder type 100 mm for cut concrete and steel

2.2.3 Colour spay (red colour)

2.2.4 Mold of concrete specimen

2.2.5 Compressive strength testing machine (in laboratory)

Figure 12 Prestressing steel type 7-wire strand, diameter 0.5 inch (12.7 mm).

(a) Guide

(b) Block

(c) Wedge

Figure 13 Bonded post-tensioned hard-ware and accessories**.**

(d) Sheath

(e) Tendon
(fabrication of strands and hard-ware)

Figure 13 (Continued)

(a) Hydraulic Jack

(b) HydraulicPump

Figure 14 Jacking machine consisting of hydraulic jack and hydraulic pump.

Figure 15 Grinder type 100 mm.

Figure 16 Mold of concrete Specimen.

Figure 17 Colour spay (red colour).

Figure 18 The compressive strength testing machine (in laboratory).

3. Testing Procedure

The “Test Block” specimen casted by concrete with compressive strength 320 ksc is shown in Figure 19. The dimensions of test block are 70 cm width x 250 cm length x 18 cm thick. The opening of bonded length box is prepared for testing the bonded concrete with the four values of concrete compressive strength of 240, 280, 320 and 380 ksc.

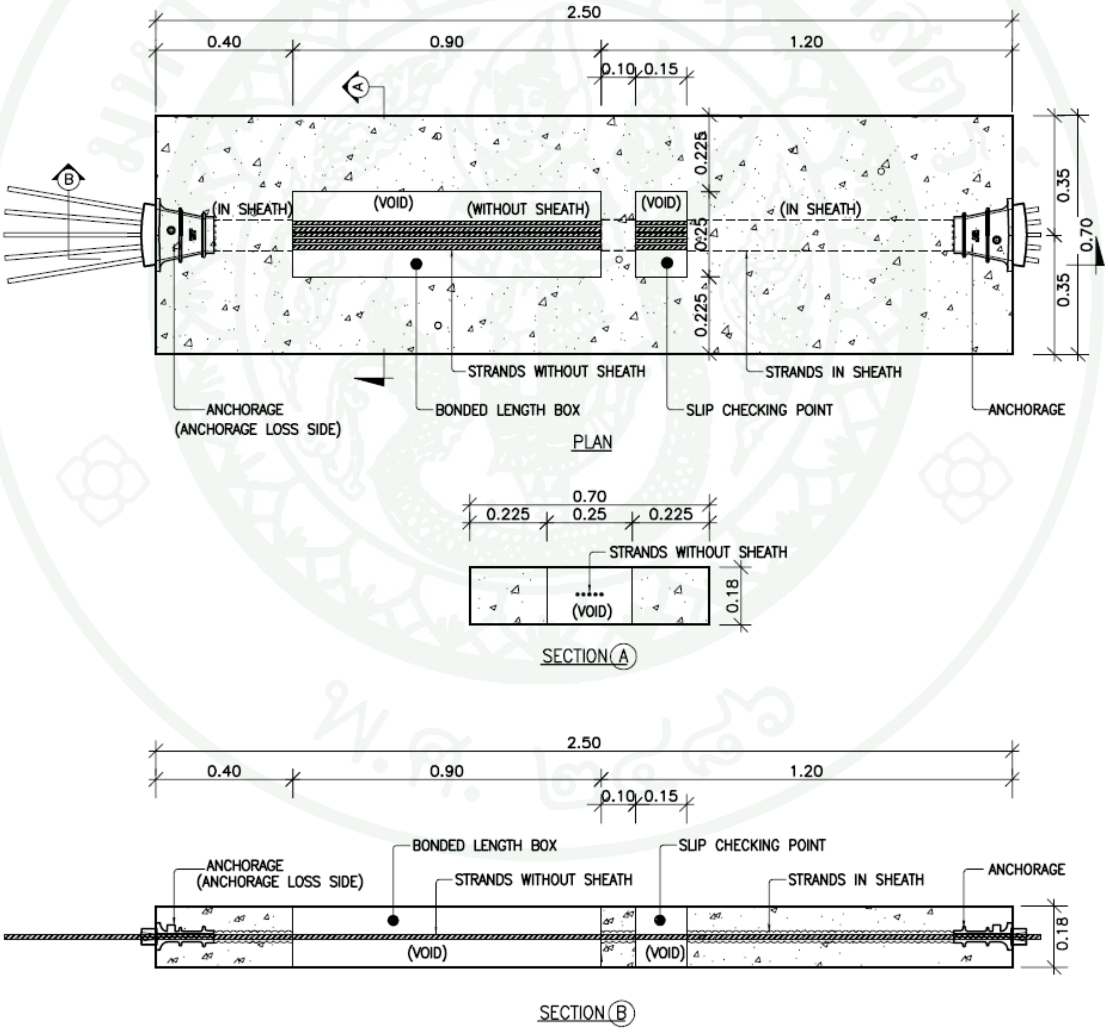


Figure 19 Detailing of “Test Block” specimen**.**

The following steps of preparation and testing are :

3.1 Prepare the test blocks as shown in Fig.19 amount 3 specimens for each type of concrete compressive strength. A test block consists of multiple five-strand tendon, bonded length box and slip checking point as shown in Fig.19. After, the concrete compressive strength by testing cylinder specimens are not less than 240 ksc, which is the minimum compressive strength of concrete at jacking force, start to stress strands as step 3.2. The “test block” specimen is prepared as in the steps following Fig.20 to Fig.26.

Figure 20 Preparation of formwork, reinforcing of rebar and fabrication of tendon with post-tensioned hard-ware composed of sheath and 1st part of anchorage (Guide).

Figure 21 Casting of concrete compressive strength 320 ksc (cylinder).

(a) *(b)*

Figure 22 Removing of formwork *(a)*, then curing of the test block *(b)*.

(a) *(b)*

Figure 23 Installation of multiple five-strands into the test block.

Figure 24 Fabrication of 2nd part of anchorage (block).

(b)

(a)

Figure 25 Fabrication of wedges into holes of block.

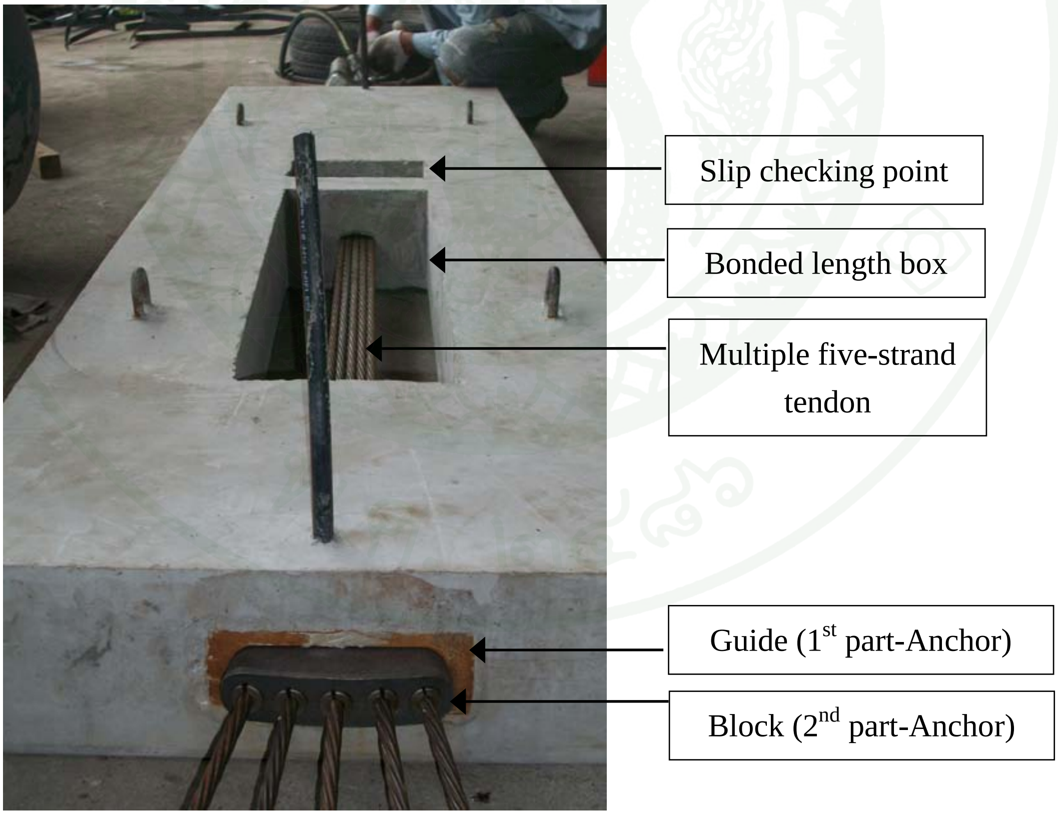


Figure 26 The completion preparation of “Test Block” specimen.

3.2 Stressing all strands as shown in Fig.27. Jacking force in each strand is 15.0 tons which is the maximum jacking force of 7-wire strand dia. 0.5 inch (12.7 mm) in field work. The stressing force measured by the gauge reading bar is calculated from the calibration equation of hydraulic jack and pump as shown in Appendix.

(a) Stressing of 15.0 ton/strand by jacking machine.

(b) Gauge reading bar

(c) During Jacking

Figure 27 Stressing all strands by jacking machine (hydraulic jack and pump).

3.3 Casting of the concrete with compressive strength that is specified in test procedure into the bonded length box to cover multiple five-strand tendons as shown in Fig.28. After completion of the first test, vary the length in order to evaluate the minimum length of concrete for each type of compressive strength from data recording in step 3.7 and step 3.8 as shown in Fig.29.

Figure 28 Casting of concrete in to the bonded length box.

Figure 29 Varying the length of concrete to determine the min. bonded length.

3.4 Sampling concrete for compressive strength test of covering concrete in bonded length box as shown in Appendix. Molded and cured specimens of concrete are tested to determine compressive strength before starting step 3.6.

(a) Sampling concrete for compressive strength test

(b) Compressive strength test to refer to strength of concrete in bonded length box.

Figure 30 Sampling for compressive strength test of concrete in bonded length box.

3.5 Spray colour on all strands as shown in Fig.31 to mark the reference point for checking slip later in step 3.7. The Fig.32 shows the picture to compare in case the test slip occurs in step 3.7.

Figure 31 Spraying colour on strands to mark the reference point.

Figure 32 The comparison with Fig.31 in case the test slip occurs in step 3.7.

3.6 Cutting anchorage to release anchorage force at right end anchorage as shown in Fig.33. The cutting of anchorage is very difficult so the test is adjusted by cutting all strands near anchorage. This leads to transfer of the anchorage force to the covering concrete in bonded length box as shown in Fig.34.

(a)

(b)

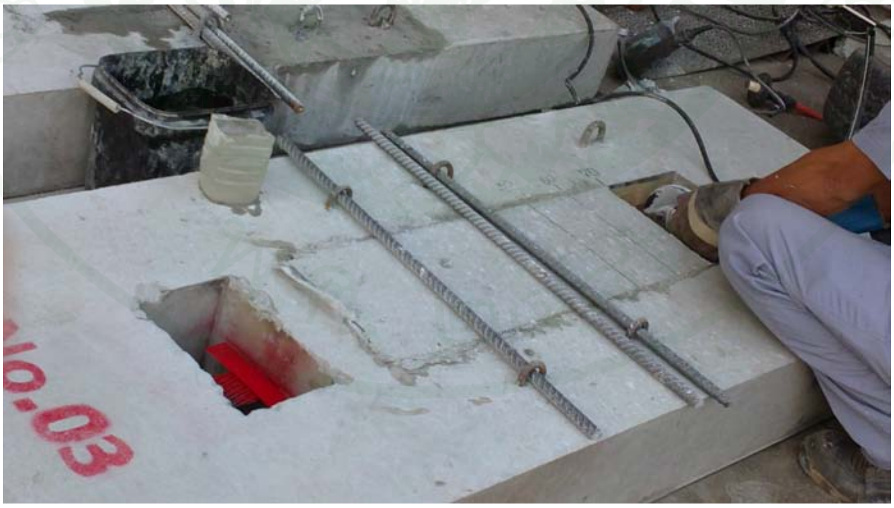


Figure 33 Release force of the right end anchorage by cutting all strands.

(a) Cutting all strands at the right end anchorage. Anchorage force transfer to the concrete in bonded length box

(b) Force at anchorage reduced to zero.

Figure 34 After cutting strands, the anchorage force transfers to the concrete in bonded length box.

3.7 After transfer of force, check the slip of each strand at slip checking point carefully and refer to the reference point in step 3.5 as shown in Fig.35*a*, Fig.35*b* and Fig.35*c* and wait to observe 30 minutes and up to 60 minutes. If the slip of all strands is zero, it is reasonable to conclude that it has enough bonded development lengths. If the slip of some strand occurs, it indicates that the length of bonded strength of covering concrete for that compressive strength is not enough.

(a) Checking the slip in slip checking point at left end after transfer the anchorage force and refer to the marking reference point in step 3.5 as shown in *(b)* and *(c).*

(b) For case no slip

(c) For case slip occurs

Figure 35 Checking the slip in slip checking point after transfer the anchorage force.

3.8 If all strands in step 3.7 do not have slip, decrease the length of covering concrete in bonded length box by cut the covering concrete out 10 cm, step by step, as shown in Fig.36*a* and Fig.36*b*. At each step of cutting, check the slip of all strands as in step 3.7 to determine the minimum length of covering concrete for each type of compressive strength that does not slip.

(a) Cutting of the concrete 10 cm, step by step, to decrease the bonded length.

(b) Each step of 10 cm cutting, step by step, checking slip as in step 3.7

Figure 36 Decreasing the length of bonded concrete as 10 cm step by step.

Figure 37 shows the slip occurs after cutting each 10 cm of bonded concrete. The minimum bonded length means that the last bonded length of concrete with no slip occurs on strands as shown in the previous Fig.36.

(a) The slips occurred during the time of cutting of concrete at step 50 cm to 40 cm.

(b) The slips of all five-strands occurred at the same time.

Figure 37 Cutting of the concrete 10 cm, step by step, until the slip occurs.

3.9 Repeat the tests from step 3.2 to step 3.8 for the concrete compressive strength 240, 280, 320 and 380 ksc that are specified in test procedure and determine the minimum bonded length of concrete. Fig.38 shows the 3 specimens of the test block of multiple five-strand tendons after tests. Fig.39*(a)* and Fig.39*(b)* show failures of covering concrete in bonded length box after test.

Figure 38 The 3 specimens of the test block of multiple 5-strand tendons after test.

(a) Shows a failure of concrete at bonded length box after test.

(b) Shows a failure of concrete in bonded length box after test.

Figure 39 The failures of covering concrete in bonded length box of multiple five-strand tendons after test.

3.10 For comparison that the bonded length of the largest type, multiple five-strand tendons, is more critical than the smaller types and conservative to be representative type of multiple two and up to five-strand tendon, repeat all steps of the test and use the multiple three-strand tendons instead of multiple five-strand tendons and compare the results from test. Fig.40 shows the 3 specimens of the test block of multiple three-strand tendons after tests. Fig.41 shows a failure of covering concrete in bonded length box after test.

Figure 40 The 3 specimens of the test block of multiple 3-strand tendons after test.

Figure 41 A failure of covering concrete in bonded length box of multiple three-strand tendons after test.

RESULTS AND DISCUSSION

The bonded length test of “Test block” of multiple five-strand and multiple three-strand tendons with three samples of each varied compressive strength of concrete are recorded as the results shown in Table 2.

Table 2 Test results of bonded development length of “Test block” (cm).

test no.	no. of strands	compressive strength				test of bonded length (test block)						
		spec no.	Date of Casting	fc' (ksc)	Avg. fc' (ksc)	length of bonded test at failure						
						80	70	60	50	40	30	20
1.	5-strands	1	27/12/10	323	340	P	P	P	X			
		2		375		P	P	P	X			
		3		323		P	P	P	X			
2.	5-strands	1	15/1/11	294	288	P	P	X				
		2		282		P	P	P	X			
		3		288		P	P	P	X			
3.	5-strands	1	21/1/11	236	227	P	P	X				
		2		219		P	X					
		3		225		P	P	X				
4.	5-strands	1	8/2/11	444	461	P	P	P	X			
		2		478		P	P	P	P	X		
		3		461		P	P	P	P	X		
5.	3-strands	1	29/1/11	317	280	P	P	P	P	X		
		2		265		P	P	P	P	P	X	
		3		259		P	P	P	P	P	X	
6.	3-strands	1	25/2/11	230	207	P	P	P	X			
		2		196		P	P	P	X			
		3		196		P	P	P	X			
7.	3-strands	1	3/3/11	311	323	P	P	P	P	P	P	X
		2		317		P	P	P	P	P	P	X
		3		340		P	P	P	P	P	X	

The meaning of “P” is the length of covering concrete in bonded length box after cutting the covering concrete out 10 cm and all strands are not slip, step by step, follows the testing procedure. The meaning of “X” is the last length of covering concrete in bonded length box where slip occurred and can not be finished to cut the covering concrete out 10 cm and waiting to observe 30 minutes and up to 60 minutes.

The test results of bonded length in Table 2 can be recommended as the minimum bonded length at failure for varied compressive strength of concrete as shown in Table 3.

Table 3 Minimum bonded length at failure from test of multiple five-strand and multiple three-strand tendons of each type of compressive strength.

fc' (cylinder)	minimum bonded length at failure (cm.)	
(ksc)	5-strand tendons	3-strand tendons
450	60	-
320	60	40
280	70	50
240	80	60

Table 3 shows the minimum bonded length at failure from test of multiple five-strand and multiple three-strand tendons for the jacking force of 15.0 ton that is the maximum permissible tensile stress ($0.8f_{pu}$) due to prestressing steel jacking force in section 18.5.1 of ACI 318-08. The lengths at failure from test in Table 3 can be applied to be the transfer length of multiple five-strand tendons by using strength reduction factor 0.75 which is recommended as ϕ value in 9.3.2.7 of ACI 318-08. The transfer length which is a distance of transfer at each end of the tendons to perform the function of anchorage, when mechanical end anchorages are not provided, is shown in Table 4.

The effective force of strand is less than the jacking force of 15.0 ton from losses. The total losses are from two stages of loading. The first stage is immediately following transfer of prestress force to the concrete members that are elastic shortening of concrete, anchorage slip and friction loss. The second stage is at service load after all losses of prestressing have occurred. This long-term effective prestress level includes creep of concrete, shrinkage of concrete and steel relaxation. The total estimation of all prestress losses in practical design work of post-tensioned concrete floors are 22.3% of the ultimate strength (f_{pu}) of prestressing strand. Therefore the effective force that is typically used is 10.80 ton.

The steel tendons have to carry the critical force of prestressing strands to transfer load at ultimate state. The minimum bonded length at failure from test in Table 3 can be applied to be the approximate bonded development length by considering the effective force of 10.8 ton instead of jacking force of 15.0 ton and increasing the length as the linear interpolation with ultimate strength (f_{pu}) of prestressing strand 18.73 ton which is the maximum value recommended by the manufacturer of prestressing strand for strand grade 270 K diameter 0.5 inch with strength reduction factor (ϕ) of 0.75.

The approximate bonded development length of multiple five-strand tendons can be formulated into Equation (5) and Equation (6). They are used to calculate the recommended bonded development length as shown in Table 4.

$$Ld = \left(\frac{\text{Length from test}}{\phi}\right)\left(\frac{18.73}{10.80}\right) \quad (5)$$

$$L_d = \text{(length from test) (2.31)} \quad (6)$$

Table 4 shows the comparison between minimum bonded development length at failure from test, transfer length by using strength reduction factor (ϕ) of 0.75 and recommended bonded development length calculated by Equation (6).

Table 4 Comparison between minimum bonded development length at failure from test, transfer length and recommended (Equation (6)) in cm.

fc' (ksc)	5-strand tendons test	5-strand tendons transfer length	5-strand tendons recommended	3-strand tendons test	3-strand tendons transfer length	3-strand tendons recommended
450	60	80	139	-	53	92
320	60	80	139	40	53	92
280	70	93	162	50	67	116
240	80	107	185	60	80	139

For comparison, Table 5 shows the comparison of calculated transfer length and the development length between Equation (1) of ACI code and Equation (2). The transfer length of Eq.(1) should increase to develop the equal force as jacking force that is used in the test and in Eq.(2). The transfer length of Eq.(1) should increase by replacing the effective force (f_{se}) of 10.8 ton by the jacking force (f_{si}) of 15.0 ton. The calculated length by Equation (1) of ACI code does not depend on the compressive strength, f_c'.

Table 5 The comparison of the calculated transfer length (L_t) and the development length (L_d) between Eq.(1) and Eq.(2) in cm.

fc'	calculated length by Eq.(1)			calculated length by Eq.(2)	
(ksc)	L_t (f_{se})	L_t (f_{si})	L_d	L_t	L_d
450	66	91	210	52	233
320	66	91	210	78	259
280	66	91	210	91	272
240	66	91	210	109	289

Figure 42 shows the comparison between the minimum bonded length from test and transfer length of multiple five-strand tendons as shown in Table 4 with the transfer length calculated by Equation (1) and Equation (2) as shown in Table 5.

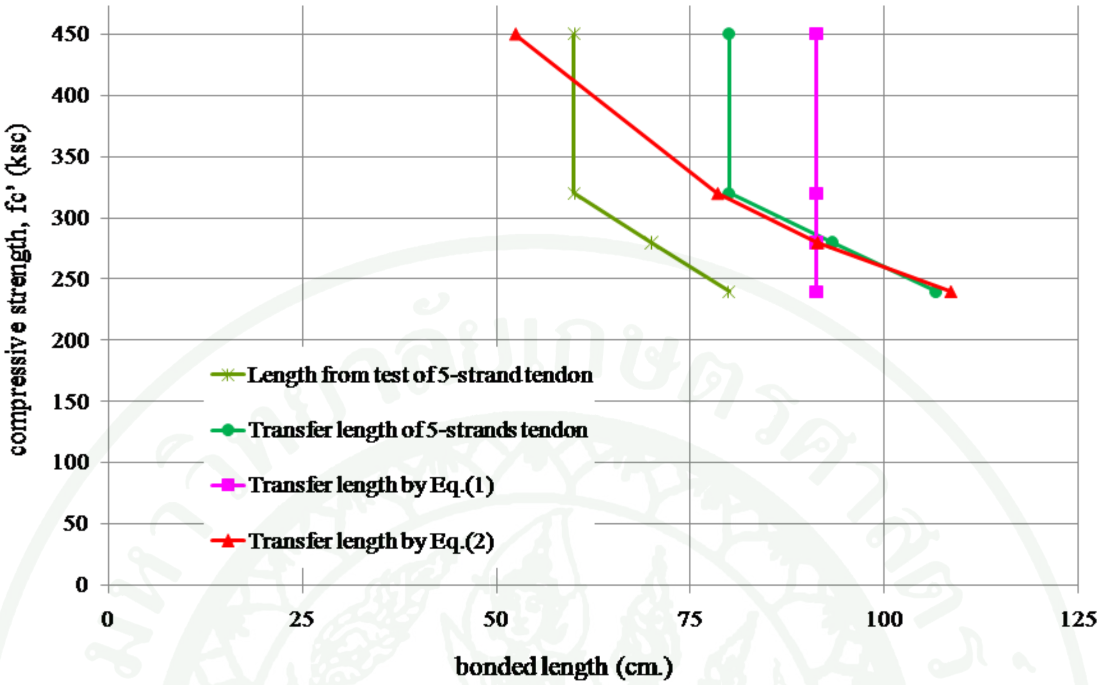


Figure 42 Comparison between the transfer length of multiple five-strand tendons with the calculated transfer length by Eq.(1) and Eq.(2).

Figure 43 shows the comparison between the recommended bonded development length of multiple five-strand tendons as shown in Table 4 with the development length calculated by Equation (1) and Equation (2) as shown in Table 5.

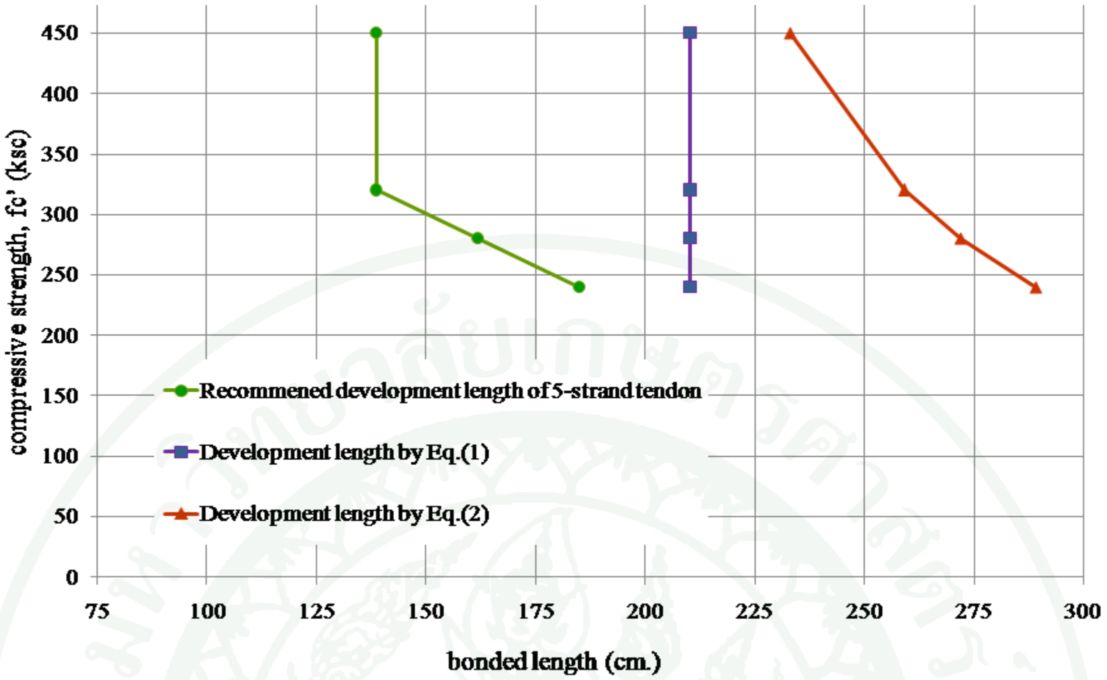
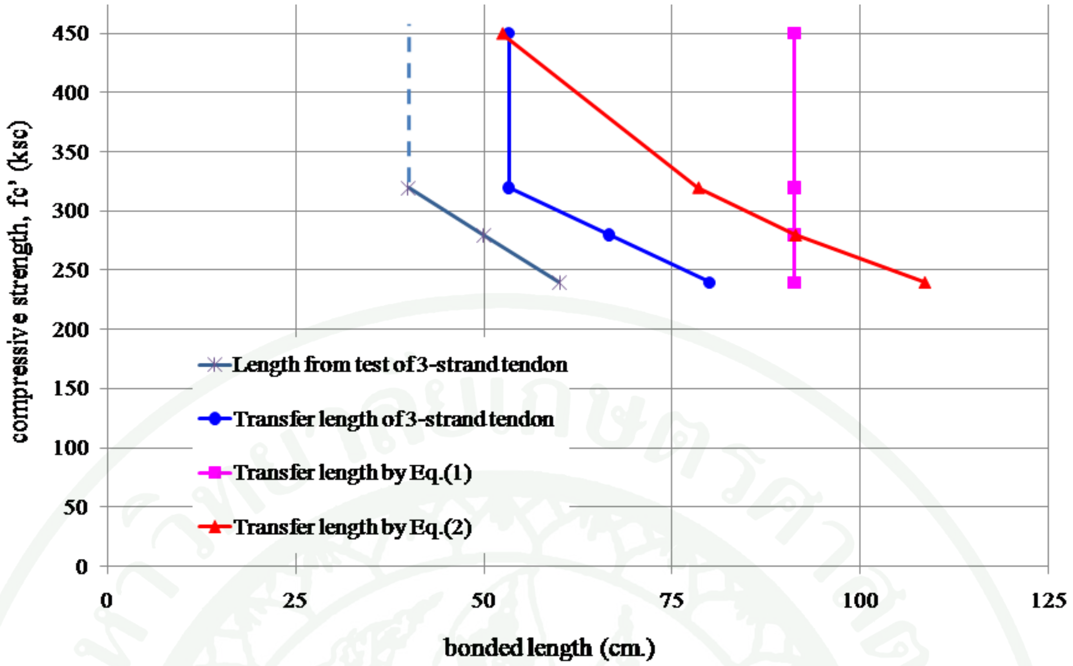
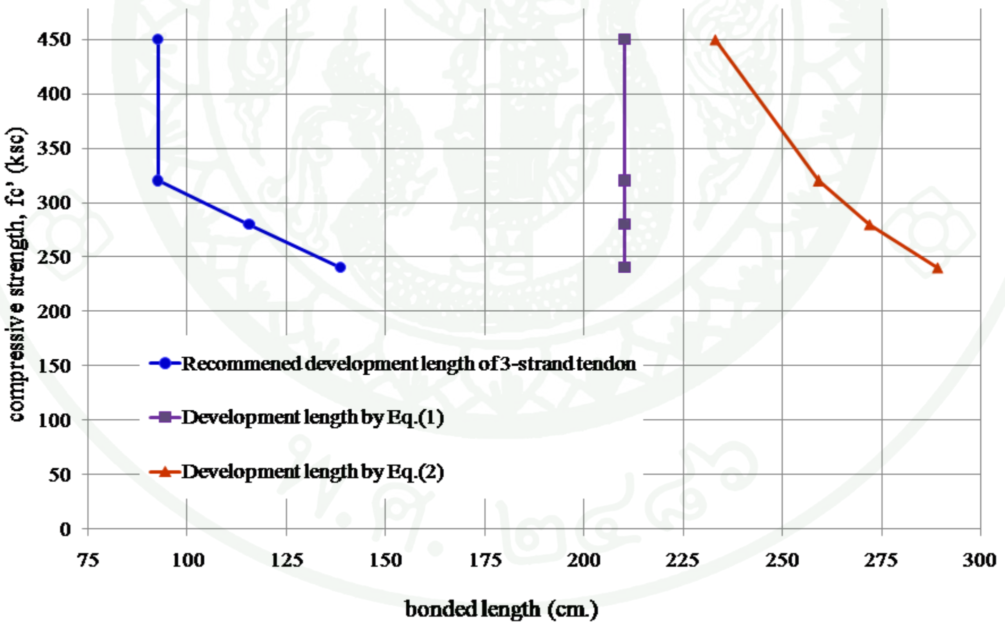


Figure 43 Comparison between the recommended bonded development length of multiple five-strand tendons with the calculated development length by Eq.(1) and Eq.(2) as shown in Table 5.

Figure 44 shows the comparison between the minimum bonded length from test, transfer length and recommended bonded development length of multiple three-strand tendons as shown in Table 4 with the transfer length and development length calculated by Equation (1) and Equation (2) as shown in Table 5. Fig.44*(a)* shows the similar comparison as Fig.42 and Fig 44*(b)* shows the similar comparison as Fig.43 but using multiple three-strand tendons in test.



(a) Comparison of the transfer length



(b)

Comparison of the recommended bonded development length

Figure 44 Comparison between the transfer length and recommended development length of multiple three-strand tendons with the calculated transfer length and development length by Eq.(1) and Eq.(2)

CONCLUSION AND RECOMMENDATION

1. The bond between the multiple five-strand tendons and covering concrete can replace anchorage stressing force as prestressing tension by using transfer length and recommended minimum bonded development length.

2. The bonded development length of multiple five-strand tendons is affected by the concrete compressive strength. The bonded development length decreases when the compressive strength of concrete increases.

3. For the comparison between the transfer length and the recommended development length from test with the computational length by ACI code equation and Lin and Burns equation, the transfer length of multiple five-strand tendons from test is close to the length of ACI code equation at the compressive strength of 280 ksc and less than ACI code equation by about 10% for the compressive strength in range of 320 ksc to 450 ksc.

4. The transfer length of multiple five-strand tendons from test is close to equation by Lin and Burns for the concrete compressive strength in range of 240 ksc to 320 ksc.

5. The recommended bonded development length of multiple five-strand tendons is less than both equations. It can be explained that the test does not include the long term effects, i.e. , shrinkage, creep, bond stress produced by flexural, shear and cracks.

6. The bonded development length of multiple 5-strand tendons is longer than the multiple 3-strand tendons. Therefore the bonded development length of multiple 5-strand tendons can be used as the representative in practice.

LITERATURE CITED

American Association of State Highway and Transportation Officials, Inc. 1996. **Standard Specifications for Highway Bridges**. 16th ed. AASHTO, Washington D.C., The United State.

American Concrete Institute. 2008. **Building Code Requirements for Structural Concrete and Commentary (ACI 318-08) and Commentary**. ACI, Michigan, The United State.

Chompreda P. 2007. **Prestressed Concrete Design, Basic Principles**. Mahidol University, Bangkok. Available Source: http://mucc.mahidol.ac.th/~egpcp/Handout406/40609%20Prestressed.pdf, April 8, 2011

Gupta P. R. n.d. **Design and Construction of Post-Tensioned Concrete Structures**. Post-Tensioned Institute, Michigan, The United State.

Lin T. Y. and N. H. Burns. 1982. **Design of Prestressed Concrete Structures.** 3rd ed. John Wiley & Sons, Inc, New York, The United State.

Post & Precast co., Ltd. 2003. **Method Statement of Post-Tensioned Slab.** Department of Engineering, Post & Precast co.,Ltd., Bangkok.

Precast/Prestressed Concrete Institute. 2004. **PCI Design Handbook**. 6th ed. PCI, Chicago, Illinois, The United State.

Sengupta A. K. and D. Menon. n.d. **Prestressed Concrete Structures**. Indian Institute of Technology Madras, India. Available Source: http://nptel.iitm.ac.in/courses/IIT-MADRAS/PreStressed_Concrete_Structures/index.php, April 2, 2011.

Siam Cement Group. n.d. **CPAC Precast Products**. n.p. (in Thai)

APPENDIX

Doc. No. S0728B-10

AIT

Asian Institute of Technology
Km. 42 Paholyothin Highway, Klong Luang, Pathumthani, Thailand 12120
P. O. Box 4 Klong Luang, Pathumthani, Thailand 12120. Tel.(66-2) 524-5527, 524-6427 Fax.(66-2) 524-5544

STRUCTURAL ENGINEERING LABORATORY
STRUCTURAL ENGINEERING FIELD OF STUDY
SCHOOL OF ENGINEERING AND TECHNOLOGY

TYPE OF TEST: **CALIBRATION TEST**

TEST SPECIMEN: The testing machine consists of the hydraulic jack of serial no. J.26 and the "POWER TEAM" hydraulic pump of serial no. 332921 (P.26) fitted with the "NUQVA FIMA" pressure gauge having a maximum capacity of 600 bar or 8,000 psi.

CLIENT: **POST & PRECAST CO., LTD.**

DATE OF TEST: November 12, 2010

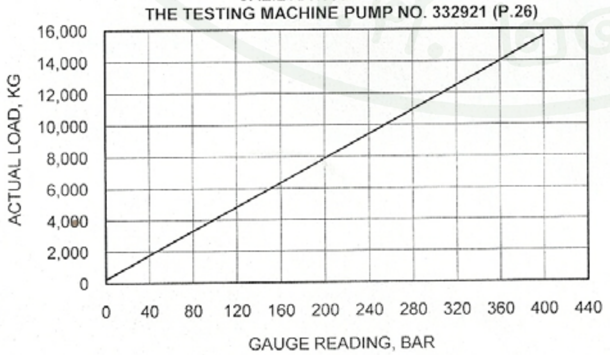
TEST APPARATUS: The test apparatus consists of a 30-ton standard load cell, "TML" type : CLC-300KNA, serial no. ALG03006, and a portable data-logger TDS-303, serial no. 0802030, manufactured by "Tokyo Sokki Kenkyujo Co., Ltd.".

TEST RESULTS:

Gauge Reading (bar)	Actual Load Readings (tonf)				Actual Load (kg)	Remarks
	Test No. 1	Test No. 2	Test No. 3	Average		
0	0.00	0.00	0.00	0.00	0	The specimen was calibrated in the
80	3.19	3.26	3.18	3.21	3,210	range of 80 to 400 bar.
120	4.78	4.78	4.86	4.81	4,807	The calibration equation should be
160	6.33	6.39	6.32	6.35	6,347	used in the calibration range only.
200	7.94	8.09	8.04	8.02	8,023	
240	9.36	9.53	9.47	9.45	9,453	kgf = kilogram - force
280	10.92	11.09	10.85	10.95	10,953	kN = kilo - Newton
320	12.46	12.52	12.48	12.49	12,487	
360	13.95	13.96	13.97	13.96	13,960	
400	15.53	15.55	15.50	15.53	15,527	

Note : This report certifies the adequacy and representative character of the test sample(s) only.

CALIBRATION CURVE OF
THE TESTING MACHINE PUMP NO. 332921 (P.26)



THE CALIBRATION EQUATION:
Actual Load, kgf
= Gauge Reading, bar x 38.3069 + 224.8519
TESTED BY: MR. RUNGROJ J. Rng.J.
CHECKED BY: MR. EKKACHAI Y.
APPROVED BY:

DR. PENNUNG WARNITCHAI
ASSOCIATE PROFESSOR
FIELD COORDINATOR OF STE/SET
November 23, 2010

Appendix Figure 1 Calibration test result of hydraulic jack and hydraulic pump.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from: บริษัท โพส แอนด์ พรีคาส จำกัด

Date of testing :

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,980	27/12/2553	6/1/2554	10	-	57,085	323	พื้น
2	Ø15x30	13,100	27/12/2553	6/1/2554	10	-	66,259	375	พื้น
3	Ø15x30	13,000	27/12/2553	6/1/2554	10	-	57,085	323	พื้น

Tested by: สมบูรณ์ จินดาราม

(นายสมบูรณ์ จินดาราม)

Engineer:

(นายอมเรศ บกสุวรรณ)

Certified by:

(ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)

หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.

2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 2 The result of compressive strength test of test no.1.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,840	15/1/2554	18/1/2554	3	-	51,988	294	พื้น
2	Ø15x30	12,950	15/1/2554	18/1/2554	3	-	49,949	283	พื้น
3	Ø15x30	12,870	15/1/2554	18/1/2554	3	-	50,968	288	พื้น

Tested by: (นายสมบูรณ์ จินดาราม)

Engineer: (นายอมเรศ บกสุวรรณ)

Certified by: (ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)
หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.
2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 3 The result of compressive strength test of test no.2.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,950	21/1/2554	26/1/2554	5	-	41,794	236	พื้น
2	Ø15x30	12,820	21/1/2554	26/1/2554	5	-	38,736	219	พื้น
3	Ø15x30	12,880	21/1/2554	26/1/2554	5	-	39,755	225	พื้น

Tested by: สมบูรณ์ จินดาราม

(นายสมบูรณ์ จินดาราม)

Engineer:

(นายอมเรศ บกสุวรรณ)

Certified by:

(ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)

หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.

2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 4 The result of compressive strength test of test no.3.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	13,130	8/2/2554	22/2/2554	14	-	78,491	444	พื้น
2	Ø15x30	13,230	8/2/2554	22/2/2554	14	-	84,608	479	พื้น
3	Ø15x30	13,300	8/2/2554	22/2/2554	14	-	81,549	461	พื้น

Tested by: สมบูรณ์ จินดาราม
(นายสมบูรณ์ จินดาราม)

Engineer:
(นายอมเรศ บกสุวรรณ)

Certified by:
(ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)
หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.
2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 5 The result of compressive strength test of test no.4.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,980	29/1/2554	1/2/2554	3	-	56,065	317	พื้น
2	Ø15x30	13,050	29/1/2554	1/2/2554	3	-	46,891	265	พื้น
3	Ø15x30	13,000	29/1/2554	1/2/2554	3	-	45,872	259	พื้น

Tested by: (นายสมบูรณ์ จินดาราม)

Engineer: (นายอมเรศ บกสุวรรณ)

Certified by: (ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)
หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.
2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 6 The result of compressive strength test of test no.5.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,860	25/2/2554	28/2/2554	3	-	40,775	231	พื้น
2	Ø15x30	12,720	25/2/2554	28/2/2554	3	-	34,659	196	พื้น
3	Ø15x30	12,710	25/2/2554	28/2/2554	3	-	34,659	196	พื้น

Tested by: (นายสมบูรณ์ จินดาราม)

Engineer: (นายอมเรศ บกสุวรรณ)

Certified by: (ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)
หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.
2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 7 The result of compressive strength test of test no.6.

STRUCTURE AND MATERIAL TESTING

DEPARTMENT OF CIVIL ENGINEERING: RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI

COMPRESSION TEST

Project:

Specimens from : บริษัท โพส แอนด์ พรีคาส จำกัด

Type of specimen: คอนกรีตทั่วไป (ทรงกระบอก)

Specimen No	Nominal Size cm	Weight g	Date of Casting dd/mm/yy	Date of Testing dd/mm/yy	Age of Specimen day	Slump cm	Maximum Load kg	Compressive Stress ksc	Remark
1	Ø15x30	12,740	3/3/2554	17/3/2554	14	-	55,046	311	
2	Ø15x30	12,780	3/3/2554	17/3/2554	14	-	56,065	317	
3	Ø15x30	12,750	3/3/2554	17/3/2554	14	-	60,143	340	

Tested by: (นายสมบูรณ์ จินดาราม)

Engineer: (นายอมเรศ บกสุวรรณ)

Certified by: (ผู้ช่วยศาสตราจารย์ประกาศ ทองประไพ)
หัวหน้าภาควิชาวิศวกรรมโยธา

Remarks: 1. The testing results are good only for those specimens tested.
2. Not valid unless be signed.

PAGE 1/1

Appendix Figure 8 The result of compressive strength test of test no.7.

CIRRICULUM VITAE

NAME : Mr. Wiroj Atipornwanich

BIRTH DATE : September 23, 1968

BIRTH PLACE : Bangkok, Thailand

EDUCATION :

YEAR	INSTITUTE	DEGREE / DIPLOMA
1991	Kasetsart Univ.	B.Eng. (Civil Engineering)
2011	Kasetsart Univ.	M.Eng. (Civil Engineering)

POSITION/TITLE : Director

WORK PLACE : Post & Precast co.,Ltd. Bangkok.